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Research Article

Product Acceptance Determination with Measurement Error Using the Neutrosophic Statistics

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The variable data is obtained from the measurement process which is not fully complete or clear in nature due to measurement error. The neutrosophic statistics which is the extension of classical statistics can be applied in the industry for the lot senescing when observations or parameters are uncertain or indeterminate or unclear. In this manuscript, a new sampling plan for the measurement error using the neutrosophic statistics is designed. The proposed sampling plan has two neutrosophic parameters, namely, sample size and acceptance number. The neutrosophic operating function is also given. The neutrosophic plan parameters will be determined through the neutrosophic optimization problem. Some tables are given for some specified parameters. From the comparison study, it is concluded that the proposed sampling plan is more flexible, adequate, and effective in the uncertainty environment as compared to the existing sampling plan under the classical statistics. A real example is given for the illustration purpose.

1. Introduction

The achieving of the high quality of the product at a low cost is desired during the production process. The sampling plans have been widely used for inspecting the indeterminate or finished product. Every inspection system is based on a well-designed sampling plan and has been widely used in the industry for the lot sentencing. Using any inspection system, there is a chance for accepting a nonconforming unit or rejecting a confirming unit. Authors in [1] mentioned that this inspection error should be estimated and a corrective action by industrialist should be taken when it is large. Authors in [2] designed a sampling plan for inspection error. Authors in [3] worked on the relationship between inspection error and lot sentencing. According to [1] "The requirement that the measurement of an individual item does not exceed some specified limit is sometimes more important than the requirement that the mean and variability for the items be at or near some predetermined value". So, the acceptance sampling plan is an important tool for inspecting whether the measurement of quality interest exceeds the given specification limits or not. The sample selection process is important during the production process as the inspection cost directly depends on the size of a sample. The fate of lot is based on sample information; an accepted lot will be sent to the marker and rejected lots are recertified or bad items are replaced with good items. Several authors designed sampling plans for various aspects to study inspection error, including, for example, [1, 4–15].

In practice, usually, the experimenters are not certain about the proportion of defective product. In this case, for lot sentencing of the product, an approach called the fuzzy sampling plans can be applied for inspection of the product. The fuzzy sampling plans have been widely used in the industry for various situations. Several authors contributed in this area, including, for example, [16–32].

The existing sampling plans with measurement error are designed using the classical statistics. The classical statistics assumes precision or determinate and crisp observations in the measurement process. It was mentioned by [21] that "all observations and measurements of continuous variables are not precise numbers but more or less nonprecise. This imprecision is different from variability and errors. Therefore also lifetime data are not precise numbers but more or less fuzzy. The best up-to-date mathematical model for this imprecision is so-called nonprecise numbers". The neutrosophic statistics can be applied when the observations or plan parameters are not clear or precise. Authors in [33] introduced the neutrosophic statistics and it was applied by [34, 35]. Recently, Aslam (2018) introduced the neutrosophic statistics in the area of acceptance sampling plan. Reference [36] proposed sampling plan using neutrosophic process loss consideration with indeterminacy in plan parameters. More details about neutrosophic sampling plan can be seen in [37–39].

By exploring the literature and to the best of our knowledge, there is no work on the designing of sampling plan with measurement error using the neutrosophic statistics. In this manuscript, a new sampling plan for the measurement error using the neutrosophic statistics is designed. The proposed sampling plan has two neutrosophic parameters, namely, sample size and acceptance number. The neutrosophic operating function is also given. The neutrosophic plan parameters will be determined through the neutrosophic optimization problem. Some tables are given for some specified parameters. A real example is given for the illustration purpose.

2. Design of Proposed Plan

Suppose that a neutrosophic random variable $X_N \epsilon \{X_L, X_U\}$ follows the neutrosophic normal distribution with neutrosophic mean $\mu_N = \{\mu_L, \mu_U\}$ and neutrosophic standard deviation (NSD) $\sigma_{NX} = \{\sigma_L, \sigma_U\}$. The neutrosophic probability density (npdf) of the neutrosophic normal distribution is defined by [33] and given by

$$X_N \sim N_N(\mu_N, \sigma_N) = \frac{1}{\sigma_N \sqrt{2\pi}} \exp\left(-\frac{(X_N - \mu_N)^2}{2\sigma_{NX}^2}\right); \quad X_N \epsilon \{X_L, X_U\}, \ \mu_N = \{\mu_L, \mu_U\}, \ \sigma_N = \{\sigma_L, \sigma_U\} \tag{1}$$

The corresponding neutrosophic standard normal distribution $\Phi_N(X_N)$ is defined by

$$\Phi_N(X_N) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{X_N^2}{2}\right); \quad X_N \epsilon \{X_L, X_U\} \tag{2}$$

Suppose that ε_N is neutrosophic random error; the neutrosophic normal distribution of observed measurement $X_N = x_N + \varepsilon_N \sim N_N(\mu_N, \sigma_{X_N}^2)$. Suppose that ρ_N be the neutrosophic correlation between true neutrosophic observation and observed neutrosophic observation. By following [1], ρ_N is defined by

$$\rho_N = \frac{E_N\left\{(X_N - \mu_N)^2 + (X_N - \mu_N)\varepsilon_N\right\}}{\sigma_{Np}\sigma_{NX}}; \quad \varepsilon_N \epsilon \{\varepsilon_L, \varepsilon_U\} \tag{3}$$

where σ_{Np} is NSD of observed neutrosophic measurement.

Note here that ε_N and x_N are independent, so ρ_N can be defined by

$$\rho_N = \frac{\sigma_{Np}}{\sigma_{NX}}; \quad \sigma_{Np} \epsilon \left\{\sigma_{Lp}, \sigma_{Up}\right\}, \ \sigma_{NX} \epsilon \{\sigma_{LX}, \sigma_{UX}\} \tag{4}$$

The correlation between the size of measurement error r_N and ρ_N is given by

$$\rho_N = \frac{r_N}{\sqrt{1 + r_N^2}} \tag{5}$$

where $r_N = \sigma_{Np}/\sigma_{N\varepsilon}$.

The quality of interest beyond the upper specification limit (U) or the lower control limit (L) is called the nonconforming item. We suppose that the quality of interest has some unclear or indeterminate observations. Based on the above information, we propose the following sampling plan

Step 1. Specify r_N and calculate ρ_N.

Step 2. Take a random sample $n_N \epsilon \{n_L, n_U\}$ from the submitted lot and compute statistic $J_N = (U - \overline{X}_N)/s_{Np}$; $\overline{X}_N \epsilon \{\overline{X}_L, \overline{X}_U\}$; $\overline{X}_L = \sum_{i=1}^{n} x_i^L/n_L$, $\overline{X}_U = \sum_{i=1}^{n} x_i^U/n_U$ and $s_{Np} = \{s_{Lp}, s_{Up}\}$, where $s_{Lp} = \sqrt{\sum_{i=1}^{n}(x_i^L - \overline{X}_L)^2/n_L}$ and $s_{Up} = \sqrt{\sum_{i=1}^{n}(x_i^U - \overline{X}_U)^2/n_U}$; $i = 1, 2, 3, \ldots, n$.

Step 3. Accept the lot of the product of $J_N \geq k_{Na}$; $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ where k_{Na} is allowed neutrosophic number of defectives.

The proposed neutrosophic plan with measurement error has two neutrosophic plan parameters, namely, sample size $n_N \epsilon \{n_L, n_U\}$ and neutrosophic acceptance number $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$. The proposed neutrosophic plan with measurement error is extension of [1] plan. The proposed neutrosophic plan with measurement error reduces to [1] when $n_L = n_U$ and $\{k_{La} = k_{Ua}\}$.

The neutrosophic operating function (NOF) of the proposed neutrosophic plan is derived in the following steps.

According to the operational process of the plan, the lot of product will be accepted if

$$P(J_N \geq k_{Na}) = P\left(\frac{U - \overline{X}_N}{s_{Np}} \geq k_{Na}\right) \tag{6}$$

By following [40, 41], $\overline{X}_N \pm k_N s_N \sim N_N(\mu_N \pm c\sigma_N, \sigma_N^2/n_N + c^2\sigma_N^2/2n_N)$; the NOF of the proposed neutrosophic plan is given by

$$L_N(p) = \Phi_N\left(\left(Z_{Np_U} - k_{Na}\right)\left(\frac{1}{\rho}\right)\sqrt{\frac{n_N}{1 + (k_N^2/2)}}\right); \quad k_N \epsilon \{k_{aL}, k_{aU}\}; \ n_N \epsilon \{n_L, n_U\} \tag{7}$$

The producer is interested in using the sampling plan such that the lot acceptance probability should be greater than $(1 - \alpha)$ at acceptable quality level (AQL=p_1), where α is producer's risk. Similarly, the consumer desires that the lot acceptance probability should be smaller than β at limiting quality level (LQL=p_2), where β is consumer's risk. To satisfy both parties risk, the neutrosophic operating characteristic curve (NOCC) should pass through the points $(1-\alpha, p_1)$ and

Table 1: The plan parameters when α = 0.05, β=0.10, r=2.

p_1	p_2	n_N	k_N	$L_N(p_1)$	$L_N(p_2)$
0.001	0.002	[359, 720]	[3.1755, 3.1941]	[0.9745, 0.9512]	[0.0741, 0.0372]
	0.003	[308, 331]	[3.1107, 3.1289]	[0.9805, 0.9723]	[0.0503, 0.0281]
	0.004	[209, 223]	[3.0170, 3.0386]	[0.9960, 0.9940]	[0.0891, 0.0550]
	0.008	[76, 99]	[2.9775, 3.0361]	[0.9679, 0.9545]	[0.0272, 0.0054]
	0.01	[43, 61]	[2.9097, 2.9755]	[0.9578, 0.9526]	[0.0651, 0.0171]
	0.015	[38, 48]	[2.7306, 2.8650]	[0.9940, 0.9805]	[0.0907, 0.0180]
	0.02	[19, 26]	[2.7619, 2.7706]	[0.9516, 0.9717]	[0.0856, 0.0517]
0.005	0.05	[31, 34]	[2.2352, 2.2713]	[0.9964, 0.9955]	[0.0976, 0.0646]
	0.1	[17, 21]	[1.9909, 2.2039]	[0.9990, 0.9909]	[0.0957, 0.0143]
0.01	0.02	[266, 349]	[2.4474, 2.4626]	[0.9513, 0.9521]	[0.0592, 0.0225]
	0.03	[90, 130]	[2.3369, 2.3841]	[0.9682, 0.9611]	[0.0976, 0.0245]
0.03	0.06	[148, 201]	[1.9973, 2.0081]	[0.9726, 0.9817]	[0.0976, 0.0501]
	0.09	[84, 95]	[1.8627, 1.9018]	[0.9965, 0.9932]	[0.0713, 0.0288]
0.05	0.1	[142, 152]	[1.7578, 1.7894]	[0.9915, 0.9804]	[0.0911, 0.0403]
	0.15	[53, 57]	[1.6799, 1.7049]	[0.9811, 0.9741]	[0.0374, 0.0216]

Table 2: The plan parameters when α = 0.05, β=0.10, r=4.

p_1	p_2	n_N	k_N	$L_N(p_1)$	$L_N(p_2)$
0.001	0.002	[382, 47]	[3.1743, 3.1901]	[0.9717, 0.9619]	[0.0841, 0.0388]
	0.003	[151, 189]	[3.1214, 3.1355]	[0.9615, 0.9646]	[0.0541, 0.0253]
	0.004	[111, 128]	[3.0364, 3.0729]	[0.9901, 0.9831]	[0.0734, 0.0288]
	0.008	[27, 67]	[2.9312, 2.9586]	[0.9528, 0.9921]	[0.0969, 0.0128]
	0.01	[38, 40]	[2.9343, 2.9605]	[0.9753, 0.9682]	[0.0240, 0.0153]
	0.015	[27, 35]	[2.7273, 2.7506]	[0.9973, 0.9987]	[0.0730, 0.0380]
	0.02	[30, 34]	[2.6201, 2.7310]	[0.9998, 0.9990]	[0.0576, 0.0126]
0.005	0.05	[27, 30]	[2.3038, 2.5092]	[0.9976, 0.9507]	[0.0270, 0.0012]
	0.1	[16, 18]	[2.2952, 2.3515]	[0.9866, 0.9800]	[0.0025, 0.0007]
0.01	0.02	[187, 256]	[2.4490, 2.4732]	[0.9631, 0.9536]	[0.0419, 0.0081]
	0.03	[73, 110]	[2.3170, 2.3883]	[0.9912, 0.9806]	[0.0889, 0.0081]
0.03	0.06	[136, 139]	[2.0164, 2.0224]	[0.9831, 0.9802]	[0.0306, 0.0243]
	0.09	[42, 87]	[1.9517, 1.9749]	[0.9566, 0.9856]	[0.0223, 0.0009]
0.05	0.1	[104, 109]	[1.7554, 1.7574]	[0.9965, 0.9969]	[0.0725, 0.0644]
	0.15	[25, 28]	[1.6484, 1.6926]	[0.9817, 0.9693]	[0.0805, 0.0384]

(β, p_2). The following neutrosophic optimization problem will be used to find the neutrosophic plan parameters.

$$\begin{aligned}
\text{minimize}\quad & n_N \epsilon \{n_L, n_U\} \\
\text{subject to}\quad & L_N(p_1) \\
& = \Phi_N\left(\left(Z_{Np_{U1}} - k_N\right)\left(\frac{1}{\rho}\right)\sqrt{\frac{n_N}{1+(k_N^2/2)}}\right) \\
& \geq 1-\alpha;\quad k_N \epsilon \{k_{aL}, k_{aU}\};\ n_N \epsilon \{n_L, n_U\} \qquad (8)\\
& L_N(p_2) \\
& = \Phi\left(\left(Z_{Np_{U2}} - k_N\right)\left(\frac{1}{\rho}\right)\sqrt{\frac{n_N}{1+(k_N^2/2)}}\right) \\
& \leq \beta
\end{aligned}$$

The purpose of the proposed neutrosophic plan is to find the neutrosophic plan parameters when $n_N \epsilon \{n_L, n_U\}$ is minimum. The neutrosophic plan parameters of the proposed plan will be determined by the grid search method. At specified values of AQL and LQL, several combinations of neutrosophic plan parameters $n_N \epsilon \{n_L, n_U\}$ and $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ will be obtained by satisfying the conditions of $L_N(p_1) \geq 1-\alpha$ and $L_N(p_2) \leq \beta$. But, the neutrosophic plan parameters where $n_N \epsilon \{n_L, n_U\}$ are selected and reported in Tables 1–3 for various values of r_N, α, β, AQL, and LQL.

From Tables 1–3, we note that $n_N \epsilon \{n_L, n_U\}$ decreases as r_N increases from 2 to 4 at the same levels of other parameters. Also, the internal between $n_N \epsilon \{n_L, n_U\}$ and $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ decreases as LQL increases. We also presented the curves of plan parameters $n_N \epsilon \{n_L, n_U\}$ and $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ when α =

Table 3: The plan parameters when $\alpha = 0.05$, β=0.10, r=6.

p_1	p_2	n_N	k_N	$L_N(p_1)$	$L_N(p_2)$
0.001	0.002	[321, 442]	[3.1959, 3.2031]	[0.9557, 0.9673]	[0.0285, 0.0086]
	0.003	[140, 165]	[3.1071, 3.1212]	[0.9872, 0.9871]	[0.0449, 0.0217]
	0.004	[70, 103]	[3.0908, 3.1093]	[0.9579, 0.9707]	[0.0330, 0.0079]
	0.008	[52, 72]	[2.8435, 2.9063]	[0.9998, 0.9998]	[0.0635, 0.0096]
	0.01	[27, 44]	[2.8700, 2.9143]	[0.9918, 0.9966]	[0.0467, 0.0075]
	0.015	[12, 24]	[2.7825, 2.8594]	[0.9761, 0.9900]	[0.0862, 0.0106]
	0.02	[18, 25]	[2.8228, 2.8240]	[0.9864, 0.9953]	[0.0096, 0.0028]
0.005	0.05	[23, 26]	[2.1799, 2.2827]	[1.0000, 0.9998]	[0.0770, 0.0157]
	0.1	[8, 13]	[2.0636, 2.1441]	[0.9984, 0.9995]	[0.0482, 0.0069]
0.01	0.02	[133, 193]	[2.4343, 2.4702]	[0.9791, 0.9649]	[0.0602, 0.0068]
	0.03	[52, 85]	[2.3580, 2.3644]	[0.9776, 0.9935]	[0.0417, 0.0112]
0.03	0.06	[65, 95]	[1.9958, 2.0166]	[0.9782, 0.9835]	[0.0916, 0.0295]
	0.09	[49, 55]	[1.9400, 1.9671]	[0.9908, 0.9854]	[0.0061, 0.0017]
0.05	0.1	[73, 84]	[1.7988, 1.8062]	[0.9827, 0.9845]	[0.0218, 0.0118]
	0.15	[44, 46]	[1.6458, 1.6630]	[0.9996, 0.9994]	[0.0134, 0.0074

0.05, β=0.05, LQL=0.001, and $r = 2, 4, 6$ in Figures 1, 2, and 3, respectively. From Figures 1–3, we note the decreasing trend in $n_N \epsilon \{n_L, n_U\}$ and $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ as AQL values increase. We also note the indeterminacy interval in parameters increases at the higher values of AQL.

3. Comparative Study

The comparison of the proposed sampling plan under the neutrosophic statistics is compared with the sampling plan proposed by [1] under the classical statistics. Reference [35] mentioned that, under the uncertainty environment, a method which provides the plan parameters in indeterminacy interval rather than the determined values is known as the most effective and adequate method. We placed the values of a sample size $n_N \epsilon \{n_L, n_U\}$ of the proposed sampling plan and n from the existing plan in Table 4. From Table 4, we note that, for the proposed sampling plan, the sample size is expressed in indeterminacy interval. For example, when AQL=0.001 and LQL=0.002, under the uncertainty environment, the experimenter can select a random sample between 359 and 720. On the other hand, the existing sampling plan provides the determined value which is 359. From the comparison, we conclude that the proposed sampling plan is more effective and flexible in the uncertainty environment than the plan under the classical statistics.

Table 4: The comparison of plans when $\alpha = 0.05$, β=0.10, r=2.

p_1	p_2	Proposed Plan n_N	Existing Plan n
0.001	0.002	[359, 720]	359
	0.003	[308, 331]	308
	0.004	[209, 223]	209
	0.008	[76, 99]	76
	0.01	[43, 61]	43
	0.015	[38, 48]	38
	0.02	[19, 26]	19
0.005	0.05	[31, 34]	31
	0.1	[17, 21]	17
0.01	0.02	[266, 349]	266
	0.03	[90, 130]	90
0.03	0.06	[148, 201]	148
	0.09	[84, 95]	84
0.05	0.1	[142, 152]	142
	0.15	[53, 57]	53

4. Industrial Example

In this section, we will discuss the application of the proposed sampling plan in the steel industry. In this industry, the measurement of tensile strength (X) is very difficult and costly. It is noted that the hardness (Y) is correlated with tensile strength and easy to study with low cost. As the data is obtained from the measurement process some observations are not precise or unclear. Furthermore, for the testing purpose, the experimenters are not sure about the random sample selection from a lot of the product. Therefore, in the testing of steel product, there is indeterminacy in variable of interest and plan parameters. So, the proposed plan can be applied when there is indeterminacy either in plan parameters or in observations or in both. Suppose that, for this testing, $\alpha = 0.05$, β=0.10, r=2, USL=200, AQL=0.001, and LQL=0.02. From Table 1, we have plan parameters $n_N \epsilon \{19, 26\}$ and $k_{Na} \epsilon \{2.7619, 2.7706\}$. Based on plan parameters information, the experimenter is decided to select a random sample $n = 21$ from the production process. The data showing some indeterminacy in variables of interest is reported in Table 5.

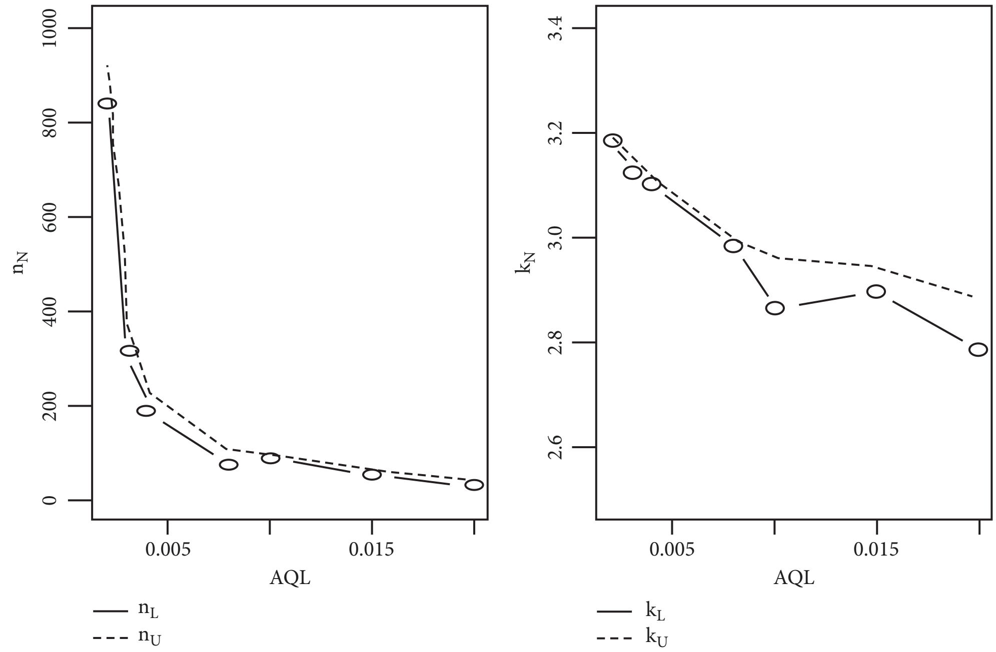

Figure 1: **Trend in** $n_N \epsilon \{n_L, n_U\}$ and $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ when α = 0.05, β=0.05, r=2.

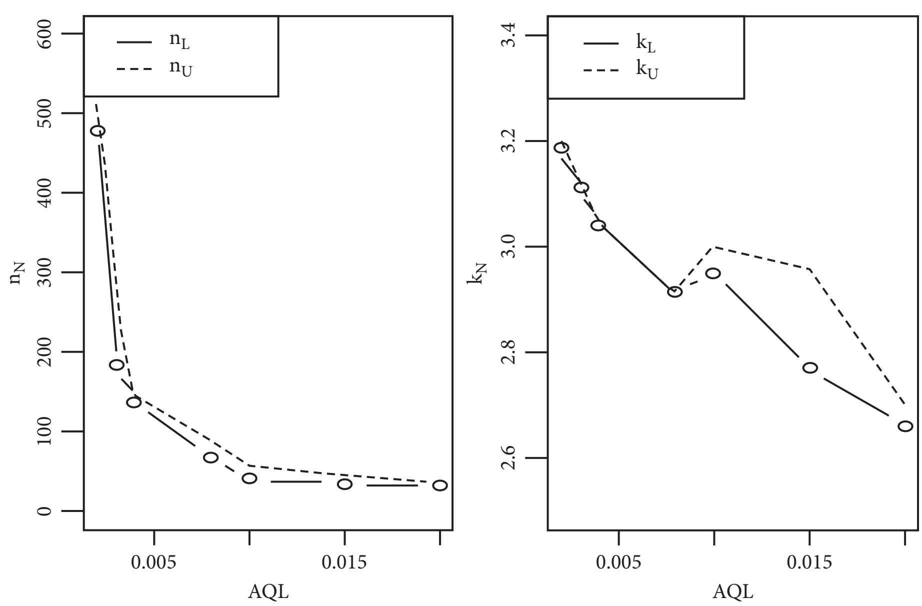

Figure 2: **Trend in** $n_N \epsilon \{n_L, n_U\}$ and $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ when α = 0.05, β=0.05, r=4.

The required statistics is given by

$$\begin{gathered} S_{Nx} \epsilon \{6.53, 19.58\}, \\ S_{Ny} \epsilon \{5.97, 19.71\}, \\ \overline{X}_N \epsilon \{51.48, 176\}, \\ \overline{Y}_N \epsilon \{52.42, 178.61\} \\ \text{and } \rho_N \epsilon \{0.81, 0.81\} \end{gathered} \tag{9}$$

The statistic J_N is computed as

$$J_N = \frac{100 - \overline{X}_N}{s_{Np}} \epsilon \{1.51, 28.05\} \tag{10}$$

The proposed plan is implemented as follows.

Step 1. Specify $r_N \epsilon \{2, 2\}$ and calculate $\rho_N \epsilon \{0.81, 0.81\}$.

Step 2. Take a random sample $n_N \epsilon \{21, 21\}$ from the submitted lot and compute statistic $J_N \epsilon \{1.51, 28.05\}$.

Step 3. Reject the product as $1.51 < 2.76$.

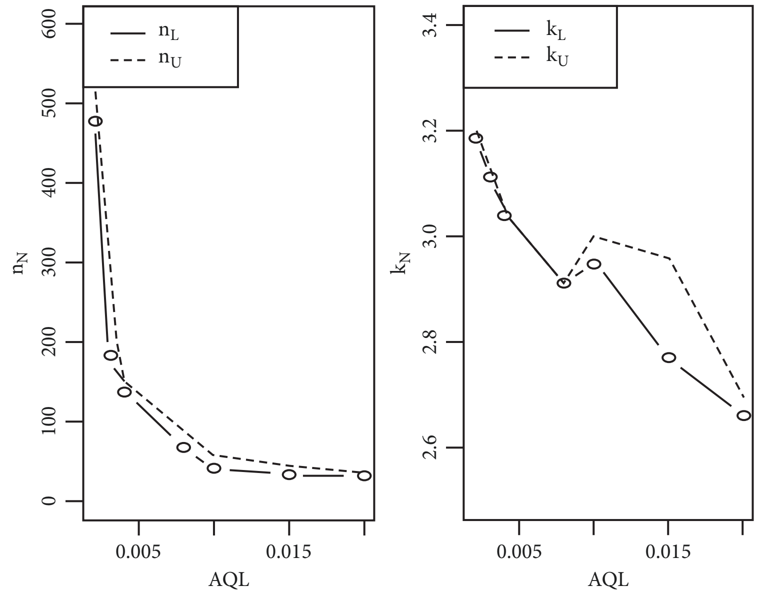

Figure 3: **Trend in** $n_N \epsilon \{n_L, n_U\}$ and $k_{Na} \epsilon \{k_{La}, k_{Ua}\}$ when $\alpha = 0.05$, β=0.05, r=6.

Table 5

X	Y
[143, 143]	[34.2, 34.2]
[200, 200]	[57, 57]
[168, 175]	[47.5, 50]
[181, 181]	[53.4, 53.4]
[148, 148]	[47.8, 47.8]
[178, 178]	[51.5, 51.5]
[162, 175]	[45.9, 50]
[215, 215]	[59.1, 59.1]
[161, 161]	[48.4, 48.4]
[141, 141]	[47.3, 47.3]
[175, 180]	[57.3, 59.6]
[187, 187]	[58.5, 58.5]
[187, 195]	[58.2, 54]
[186, 186]	[57, 57]
[172, 172]	[49.4, 49.4]
[182, 182]	[57.2, 57.2]
[170, 190]	[42, 53]
[204, 204]	[55.1, 55.1]
[178, 178]	[50.9, 50.9]
[198, 200]	[57.9, 59]
[160, 160]	[45.5, 45.5]

5. Concluding Remarks

In this manuscript, a new sampling plan for the measurement error using the neutrosophic statistics is designed. The neutrosophic plan parameters are determined and reported for the industrial application. The application of the proposed plan is shown using the steel data. The proposed plan can be applied in the industry such as in the steel industry and building testing material where the measurement data is not precise. The existing sampling plan, in this case, cannot be applied for the testing of material when indeterminacy is in the observations or parameters or both. The proposed sampling plan using other sampling schemes can be extended for future research.

Data Availability

The data is given in the paper.

Conflicts of Interest

The author declares no conflict of interest regarding this paper.

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